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LA-UR- 93-1286

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Author(s): D.E. Page, S.J. Bame, and B.G. Goldstein

Submitted to Calgary Cosmic Ray Conference, Calgary, Canada
19-30 July 1993

Los Alamos
NATIONAL LABORATORY

Solar Wind Channels for Mev Particles

D.E. Page[1], S.J. Bame[2], and B.G. Goldstein[3]
1. ESA/Ulysses Office, JPL, Pasadena, CA 91109 USA
2. Los Alamos National Lab., NM 87545, USA
3. Jet Propulsion Laboratory, Pasadena, CA 91109

ABSTRACT

Plasma, magnetic field and charged particle data from the Ulysses spacecraft is used to demonstrate that MeV particles follow channels defined by solar wind flow regimes.

1. INTRODUCTION

Energetic particles produced in solar flares travel through interplanetary space, following routes determined by the structure of the interplanetary medium. They suffer scattering at kinks in the interplanetary magnetic field and their progress in space is frequently described as diffusion, with the size and number of kinks encountered determining the mean free path. The average power spectral density of magnetic kinks has been measured and inserted in theories of particle pitch angle diffusion. Mean free paths thus calculated are about ten times smaller than mean free paths deduced from time-intensity and time-anisotropy profiles of solar particle events (eg Palmer (1982), Wanner and Wibberens (1993)).

Results are presented below which suggest that Mev solar particles can follow flow regimes in the solar wind which can provide easier than average transport conditions.

2. THE DATA

The array of Mev particle detectors on the Ulysses (Wenzel et al 1992) spacecraft has yielded many event profiles, few of which look like the classic high energy event with fast rise and slow uninterrupted decay. Rises and decays, and the intervals over which directional anisotropies endure, are interrupted by sharp discontinuities. Many particle populations appear to be bounded, or at least constrained, by heliospheric sector boundaries. An example is described below in which the parameters which best delineate the Mev particle transport appear to be solar wind plasma rather than magnetic parameters. Similar observations have been reported by Domingo et al (1976) and Anderson et al (1992).

The upper five curves of Figure 1 plot Mev proton intensities. The bottom curve - originally in four colours - gives arrival directions of 3.8 - 8.0 Mev protons in four 90° sectors. The population is clearly anisotropic from the beginning of Day 138 until Day 142 of 1991, at which time Ulysses was at 3.1 AU from the sun. This anisotropy, with particles flowing along the magnetic field and away from the sun, continues with no significant change throughout the sharp count rate drop-out of Day 139. The anisotropy is also illustrated in a pie diagram at the top of Figure 2 for protons between 1.8 and 3.8 MeV. The flux away from the sun was about 35 times greater than the flux toward the sun. (Note also the particle changes close to the heliospheric sector boundary at 0045 UT on Day 138). Figure 2 displays count rates on Day 139 for proton energies up to 92 Mev, for alpha particles and for

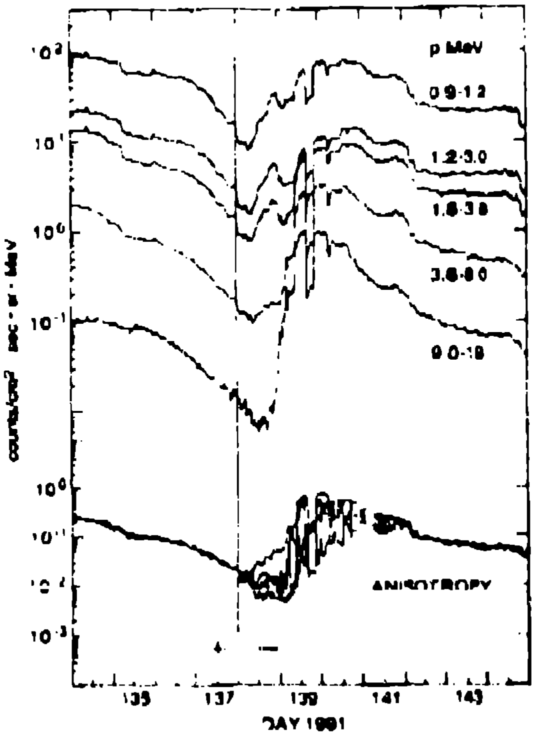
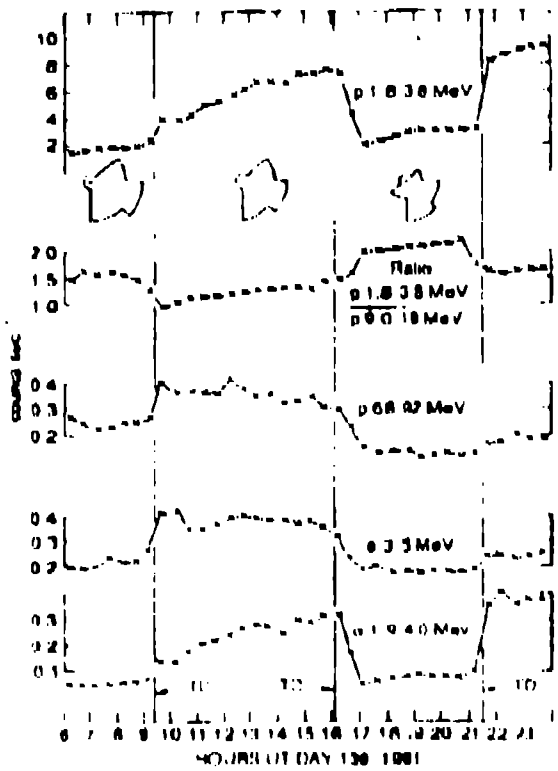


Fig 1. Proton intensities around Day 139 (May 19) of 1991. The bottom curve plots intensities in four 90° sectors for 1.8-3.8 Mev protons. The anisotropy lasts from sector boundary passage at 0045 on Day 138 until Day 142.

Fig 2. Fluxes of protons, electrons and α particles and the ratio of protons 1.8-3.8 Mev to protons 9.0-19 Mev during Day 139, 1991. Some fluxes have been adjusted for detector geometric factor, others have not. The field aligned anisotropy measured in 8 sectors is shown in the pie diagram.



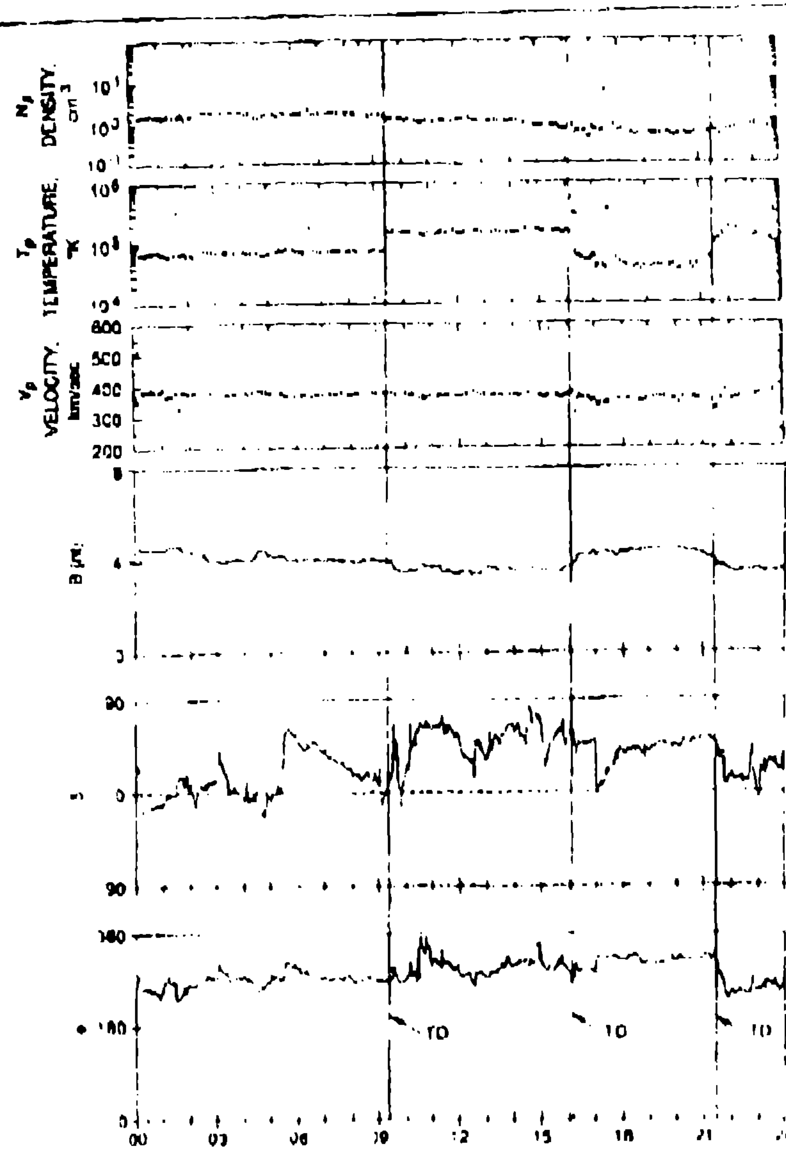


Fig 3. (Top) Solar wind proton density, temperature and velocity.
(Bottom) Magnetic field magnitude, polar and azimuth angles.

electrons. The ratio of protons 1.8-3.8 MeV to protons 9.0 19 MeV is also shown. All curves show the drop-out between about 1600 and 2130 UT. Note also a sharp increase in count rate at around 0930 UT. Corresponding solar wind and magnetic field values are shown in Figure 3. Tangential discontinuities (TDs) have been identified by the plasma and magnetic field experiments at 0925, 1610 and 2130 UT. Clearly the count rate changes correspond closely to the tangential discontinuities. (Figure 2). During Day 139 there are many changes in the magnetic field and in particular in its polar angle δ. These changes result in minor changes in proton anisotropy direction and in small changes in count rate. The significant changes in count rate however occur only when the magnetic change is accompanied by a change in the plasma parameters, indicating that a different flow regime has been encountered. The change of solar wind speed V_p is small and the direction of V_p (not shown) changes little. The parameter which seems most obviously related is the solar wind proton temperature, Tp. (Alpha temperature shows similar behaviour). Thus we find neighbouring flow regimes able to channel or to exclude protons with energies up to 90 Mev. If we think of these flow regimes crossing the spacecraft at solar wind speed, then we expect a distance equal to the gyroradious of a 10 Mev proton to be traversed in about 5 minutes. Figure 2 indicates that the boundaries between flow regimes are no wider than a few times 5 minutes.

3. DISCUSSION

Many examples with sudden flux changes similar to the above can be found in the Ulysses data. It may be that not all of the particle distributions observed have been recently produced on the sun. Some may result from shocks and interaction regions. However particle behaviour at the solar wind flow boundaries described above must be indicative of what happens when Mev solar particles propagate through the interplanetary medium. With this scenario it seems unrealistic to try to describe Mev particle propagation by diffusion through an average interplanetary scattering medium. The effectiveness of channel boundaries or flow regime boundaries in containing Mev particles is clear, but the nature of these plasma stream interfaces, how they originate and how they are preserved in space is not clear. The idea of channels or conduits in the solar wind is not new. McCracken and Ness (1966) produced similar ideas at a time when it was perhaps more difficult to line up Mev and solar plasma data for comparison. Earl (1976) considered adiabatic focusing and suggested a "supercoherent mode of particle transport". Scholer et al (1979) calculated how propagation should change from the leading edge to the trailing edge of a solar wind stream. However the concept of propagation in separate streams has frequently been overlooked in the struggle to find a universal mathematical description to fit all cases.

ACKNOWLEDGEMENTS

We thank the LASR, Chicago (J.A. Simpson, R.B. McKibben, G. Lenz, G. Popelka) and SSD, ESTEC (K-P. Wenzel, R.G. Marsden, S.T. Ho) for the charged particle data and Imperial College, London (A. Balogh, R.J. Forsyth) and JPL (E.J. Smith, J. Wolfe, L. Wigglesworth) for the magnetic field data.

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